Design of 5 K. W.-1,000 Ampere-110/5 Volt High Current Transformer

E. J. Wickersham
W. F. Parker
J. F. Kadic
A. W. Tyler

1905

AT 24
Wickersham, E. J.
Design and construction of 5 k.w. - 1,000 ampere- 110/5

DESIGN AND CONSTRUCTION OF

5 K. W. - 1,000 AMPERE - 110/5 VOLT HIGH CURRENT TRANSFORMER.

- - - - - - - - - - - -

A Thesis presented by

E. J. Wickersham.

W. F. Parker

J. F. Kadic

A. W. Tyler

to the

President and Faculty

of the

Armour Institute of Technology

for the Degree of

Bachelor of Science in Electrical Engineering

Having completed the prescribed course of study in

Electrical Engineering.

C. E. Freeman
Per Snow.

Chicago, [illegible] 18th, 1905.

H. M. Raymond.
Dean of Engineering Studies

L. C. Monin
Dean of Cultural Studies.

In the calibration of higher reading ammeters it is necessary, on account of the high current required, to use too large an amount of power to be economical when the current is supplied at the normal voltage of an ordinary A. C. generator. For this reason it is advisable to use a transformer in connection with the generator, which lowers the voltage and gives a higher current, and only changes the power by an amount equal to the losses in said transformer.

The ordinary transformers built and such as are in the labratories of technical institutions are built for transformations of about I,000 to I00, or possibly from I,000 to 50 volts. A generator, to supply current for calibration purposes, should not be larger than 4 or 5 K. W. at the most, to be economical. With this, the above transformer of I,000/I00 volts would then give a current of 50 amperes at I00 volts. Then to obtain the higher current readings requires another transformer in connection with this one. This second transformer would have to be specially designed on account of the high current at its secondary.

The transformer which we think best suited for this purpose and the design of which we have chosen for our thesis, is one to transform from II0 (pri.) to 5 volts (sec). The capacity to be such (5 K. W.) that a current of I,000 amperes may be delivered at the secondary. This will easily encompass the entire scale of the majority of the ammeters in use in any technical institution and in the various commercial uses to

which ammeters are cut; as the high reading ammeters (5,000 amperes, etc.) on the market only take a shunted current and do not take a current higher than I,000 amperes.

There is another field in which the above transformer can be used; that is, in electro-chemistry. We know that the heat developed in any circuit is represented by $I^2 R$ -- I being the current in amperes flowing in the circuit, and R the resistance in ohms of the circuit. From this we can see that to obtain the maximum amount of heat with the least expenditure of power, we must have the highest current with the lowest voltage feasible, as the power is expressed by E I -- where E is the voltage across the circuit. From this discussion it may readily be seen that the above transformer will also be valuable in the electric furnace, where currents as high as I,000 amperes are required to give the necessary heat.

In designing a transformer certain conditions are imposed under which it is to operate, as the primary and secondary voltages, capacity, frequency of alternation and minimum allowable efficiency.

There are three methods of design which are as follows:

I. Analytical Method;

II. Trial and Error Method;

III. Empirical Method.

However if the given conditions call for a design that departs considerably from previous experience, the second method is the only one available. This consists in assuming various values for B, dimensions and shape of core, current density and number of turns of wire and selecting the transformer best suited to the given conditions.

The first thing to be done in the design of a transformer is to decide upon the type and the method of cooling. We decided that the core type was the best suited to our conditions, as it would be difficult to wind such heavy wire as we would necessarily have to use for high currents, on a shell type of transformer. In regard to cooling, air cooling will give very satisfactory results when using a core type of transformer of this size.

We will now consider the general equation for a transformer, which is:-

$$E = \frac{\sqrt{2}\,\pi\,N_p\,A\,B\,f}{10^8} \text{ volts, in which}$$

E = Counter, E. M. F.

N_p= No. turns on primary,

A = Area cross section of core sq. in.,

B = Flux density (lines / □"),

f = Frequency.

The next thing to consider is, the conditions imposed upon the transformer; they are :-

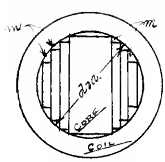
Capacity 5 K. W.

Secondary current I,000 amperes,

Primary voltage II0,

Frequency 60 cycles.

From this we can see that the only variables in the above equation are N_p, A and B. But for any value of A, B is a constant; this then narrows it down to N_p and either A. or B as the variables. As we desire to construct the transformer



with the laminated core as shown in the accompanying sketch, it is advisable to assume a certain inside diameter of coil and from this calculate the values of A and B resulting; leaving the spaces m, m for air circulation to aid in cooling.

One other variable that does not come directly into the above equation is the current density in the coils. This then leaves us with three variables to consider - - the number of turns on the primary, the diameter of core, and the density of current in coils.

We carried out a series of calculations with various

values of these variables, obtaining all data of the transformer and its efficiency under all the various conditions which we assumed. We limited the flux density in the core to 40,000 lines per sq. in. which seemed to be a maximum upper limit consistent with good practice. The following is the complete set of calculations with one set of assumptions, showing method of calculation:

Design of 5 K. W. Transformer.

The assumptions are:-

Current density - - I,000 circular mils per ampere,

Number of turns on primary I32,

Diameter core 3-I/2",

Data as given for design:-

Capacity 5 K. W.,

Current in sec. I,000 amp.

Voltage of primary II0 volts,

Frequency 60 cycles.

Primary Current (I_p)

$$I_p = \frac{E_p I_p}{E_p} = \frac{5,000}{II0} = 45.5 \text{ amperes.}$$

Size wire of primary coil.

Since I,000 circular mils / amperes are allowed in primary, and primary carries 45.5 amperes; circular mil area will be 45.5 x I,000 = 45,500 circular mils. This is equivalent to about 2 # 6 B & S wires.

(2 x 26,250 = 52,500 circular mils) will therefore be used.

Diameter = .I620 + .02 (which is the thickness of insulation) = .I820, dia. of insulated wire.

Current in secondary is I,000 amperes; then

I,000 x I,000 = I,000,000 circular mils, required for sec.

This equals 785400 square mils.

Since two secondary coils will be in parallel, we have

$$\frac{785,400}{2} = 392,700 \text{ square mils / amperes,}$$

corresponding to

2" x I/4" copper ribbon = 500,000 sq. mils.

We will use 2-I/8" ribbons in parallel.

I/4 x 3 x (.02 x 3) = .8I" depth of series winding.

(.I35 x 2) x 2 = 2.27" outside dia. of spool.

Space occupied by primary coil:-

Since the primary should have the same thickness as the secondary, then

$$\frac{.8I}{.I820} = 4+$$

Therefore we will have four layers.

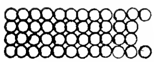
Now the capacity of the transformer 5 K. W., divided by I,000 amp. secondary current, $\frac{5,000}{I,000}$ = 5 volts in secondary. The ratio of transformation is

$$\frac{II0}{5} = 22$$

With I32 turns on the primary we have $\frac{I32}{22}$ = 6 turns on the secondary.

In regard to the spacing of the coils, the best arrangement to reduce leakage, is to interlace the primary and secondary coils. So we will arrange the coils in this order on each leg of the transformer p,s,p,s,p; which makes six primary coils and four secondary coils in all, on the two legs; I32 turns on primary, and 6 primary coils makes

$\frac{I32}{6}$ = 22 turns per coil. So we will have 22 turns of #26 B & S, #30 D. C. wire, [illegible] accompanying sketch.



Th[illegible] in all, [illegible] I2 turns wide in [illegible].

I2 x .I82" = 2.I84" [illegible] necessary for wire of one coil;

2.I84 + (.I55 x 2) = 2.45";

2.45" x 3 = 7.35" width of primary coils on one leg;

2.27" x 2 = <u>4.54"</u> " " secondary coils on one leg;

II.89" " " all coils on one leg;

Allowing .04" between each coil = (.04 x 5) = .2" for clearance;

Allowing for bringing out leads $\frac{I}{4} + \frac{I}{4}$ + 3 (.I82) = I.046".

Then total length over all coils is II.89" + .2" + I.046" = I3. I36".

Average dia. primary coil is 3.5" + 1" = 4.5";

Then length of one pri. turn is 4.5π";

length of 132 turns is $\dfrac{132 \times 4.5\,\pi}{12}$ = 155 feet.

Then we know that the resistance of any wire or rod is $R = \dfrac{\rho\, l}{A}$

where

ρ = specific mil foot resistance of copper = 12;

l = length of wire in feet;

A = area of cross section of wire in circular mils.

Then the resistance of the primary coil is

$$\frac{12 \times 155}{52500} = .0354 \text{ ohms.}$$

In the same way the resistance of the secondary coil is

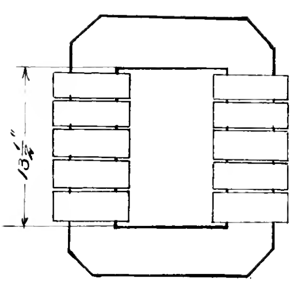
$$\frac{12 \times \left(\dfrac{8 \times \pi \times 4.5}{12}\right)}{1{,}270{,}000} = .000{,}067 \text{ ohms.}$$

~~= .000,067 ohm.~~

Then the total I^2R loss in the transformer is

$$(45.5^2 \times .0354) + (1000^2 \times .000067) = 140 \text{ watts;}$$

$$\frac{140}{5{,}000} \times 100 = 2.8\%$$ copper loss at full load.



Net area of cross section of the iron is 7.8 sq. in., allowing 10% for insulation. Length of each leg is 13.5" between the ends as shown in this sketch of iron core, which leaves about .4" for clearance at ends of coils. Then the volume of these legs is 7.8 x 13.5 x 2 = 211 cu. in. ~~We have~~

To have an area at the ends equal to 7.8, allowing for ~~champering~~ champhering, it is necessary to make the width 3". Then the volume of the two ends is 2 x 7.8 x 10.5 = 149 cu in. Total volume of iron is then - -

211 + 149 = 360 cu. in.

The formula for the hysteresis loss is - -

$$H = V_i \, f \, \eta \, B_m^{1.6} \times 10^{-7}$$

$$H = 360 \times 60 \times .002 \times 40{,}000^{1.6} \times 10^{-7} =$$

$$H = \frac{360 \times 60 \times .002 \times 23{,}100{,}000}{10^{7}} = 97.6 \text{ watts}$$

$$\frac{97.6 \times 100}{5{,}000} = 1.98\% \text{ iron loss}$$

The full load efficiency then is 100 - 2.8 - 1.98 = 95.4 % efficiency.

In the same manner we carried out the calculations with the above named assumptions. The results of the calculations are given in the following table. In the case where we assumed 38 turns on the primary coil it was found that the flux density was too high as is seen by the figures shown.

Data from calculations of 5 K. W. high current Transformer.

60 Cycles -- V_p II0 -- V_s 5 -- I_p 45. 45 -- I_s - I000

Dia."	No of turns P	S	A□"	Vcu"	$(I^2R)_p$	$(I^2R)_s$	Total I^2R%	Iron loss%	Eff %	B/□"	Coils amp.
3	I32	6	5.6	230	[illegible]	59	2.50	2.0I	[illegible]	54000	I000
3 I/4	"	"	6.7	29I	69	63	2.64	I.99	95.5	46700	I "
3 I/2	"	"	7.8	360	73	67	2.80	2.00	95.4	40000	"
3 3/4	"	"	8.6	4II	77	70	2.94	I.92	95.45	36600	"
4	"	"	9.9	474	8I	74	3.I0	I.7I	95.4	3I600	"
3	I32	6	5.6	230	56.8	45.8	2.05	2.0I	95.96	54000	I300
3 I/4	"	"	6.7	29I	60.4	48.8	2.I8	I.99	95.83	46700	"
3 I/2	"	"	7.8	360	64.I	5I.6	2.2I	2.00	95.79	40000	"
3 3/4	"	"	8.6	4II	67.5	54.2	2.43	I.92	95.65	36600	"
4	"	"	9.9	474	70.3	57.0	2.54	I.7I	95.75	3I600	"
3	I32	6	5.6	230	5I.4	39.4	I.82	2.0I	96.I7	54000	I500
3 I/4	"	"	6.7	29I	54.6	4I.8	I.93	I.99	96.08	46700	"
3 I/2	"	"	7.8	360	57.8	44.4	2.02	[illegible]	[illegible]	40000	"
3 3/4	"	"	8.6	4II	6I.[illegible]	46.8	2.I6	I.92	95.92	36600	"
4	"	"	9.9	474	64.0	49.0	2.I8	I.8I	96.0I	3I600	"
3	I76	8	5.6	230	87	78	3.3I	I.35	95.34	4I800	I000
3 I/4	"	"	6.7	29I	92	84	3.52	I.30	95.I8	35000	"
3 I/2	"	"	7.8	360	97	89	3.7I	I.26	95.03	30000	"
3 3/4	"	"	8.6	4II	I03	93.5	3.93	I.I8	94.89	27200	"
4	"	"	9.9	474	I08	97.	4.I0	.97	94.93	23600	"
3	I76	8	5.6	230	7[illegible].7	6I.0	2.73	I.35	[illegible]	4I800	I300
3 I/4	"	"	I.7	29I	80.5	64.9	2.9I	I.30	95.79	35000	"
3 I/2	"	"	7.8	360	85.5	68.6	3.08	I.26	95.66	30000	"
3 3/4	"	"	8.6	4II	90	72.4	3.2[illegible]	I.I8	95.57	27200	"
4	"	"	9.9	474	95	76.0	3.42	.97	95.6I	23600	"
3	I76	8	5.6	230	68.7	[illegible]	2.4[illegible]	I.35		4I800	I500
3 I/4	"	"	6,7	29I	72.8	58.8	2.57	I.30		35000	"
3 I/2	"	"	7.8	360	77.2	59.2	2.73	I.26		30000	"
3 3/4	"	"	8.6	4II	8I.5	62.5	2.83	I.I8		27200	"
4	"	"	9.9	474	85.0	64.0	2.93	.97		23[illegible]	"

Dia."	No of Turns P	S	□" Area	Cu." Vol	$(I^2R)_p$	$(I^2R)_s$	Total I^2R%	Iron loss%	Eff.	B/□"	Cmils per a.
3	88		5.6	230						83900	I000
3 I/4	"	"	6.7	29I						70000	"
3 I/2	"	"	7.8	360						60000	"
3 3/4	"	"	8.6	4II						54400	"
4	"	"	9.9	474						47200	"
3	88	4	5.6	230	37.I	30.5	I.35	4.55		83900	I300
3 I/4	"	"	6.7	29I	40.4	32.3	I.45			70000	"
3 I/2	"	"	7.8	360	42.6	34.4	I.54			60000	"
3 3/4	"	"	8.6	4II	45.I	36.2	I.62			54400	"
4	"	"	9.9	474	48.10	38.I	I.72			47200	"
3	88	4	5.6	230	34.4	26.3	I.2			83900	I500
3 I/4	"	"	6.7	29I	35.7	27.9	I.29			70000	"
3 I/2	"	"	7.8	360	38.5	28.6	I.34			60000	"
3 3/4	"	"	8.6	4II	40.3	31.2	I.45			54400	"
4	"	"	9.9	474	42.2	32.8	I.50			47200	"

Flux Density too high

From these calculations we decided to use the 3 1/2" core with 132 turns on the primary and six turns on the secondary and with a current density of 1500 circular mils per ampere.

It has been found by experience that for a transformer operating under full load conditions, the iron losses should be made practically equal to the copper losses for best results. The calculations made with the above chosen assumptions, giving the best efficiency, also answer these conditions.

The next thing we did was to obtain a test ring of laminated iron of the quality which we expect to use in the construction of the transformer, and insulated in the same manner. On this ring were wound a primary and a secondary coil.

We decided to first obtain a B - H. curve for the iron in this sample ring, in order to ascertain whether the quality was of a suitable grade to be used in the construction of the transformer core. In order to do this it was necessary to make use of a ballistic galvanometer, in the Ewing's Ring Method of Determining a B - H. curve.

Before using this galvanometer we found that it was necessary to accurately obtain its constant K, which constant represents the deflection, in millimeters, of the moving system of the galvanometer, upon the application of one coulomb of electricity, at its terminals.

The method used to determine this constant was to charge a standard one-third microfarad condenser at certain known voltages

and then discharge same through the galvanometer [illegible] the resultant deflection

Then we have

$$Q = K\rho$$

$$\& \quad Q = C\,E$$

Hence $\quad K\rho = C\,E$

$$K = \frac{C\,E}{\rho}$$

Where Q = quantity in coulombs

K = galvanometer constant

C = capacity in farads

E = E. M. F. in volts

ρ = Deflection in mm

The results we obtained were as follows:-

Voltage	ρ in mm.	ρ per volt
I	72	72
2	I52	76
3	2I7	72
4	270	75

Average ρ per volt = 74.

Substituting in above equation for K, we have $K = \frac{\frac{1}{3} \times 10^{-6} \times 1}{74} = 45 \times 10^{-10}$

Having obtained this constant we then proceeded to determine the B-H curve. To do this we sent a known current through the primary coil, which gives a value of H, which can be calculated from the formula $H = \frac{4\pi n_1 I}{10 l}$, where

H = strength of field

n_p = number of turns on primary coil

I = current in amperes in " "

l = mean length of ring in cm.

Then the flow of the current in the primary induces a current in the secondary which causes a deflection of the moving system of the galvanometer. From this we can calculate the value of B corresponding to this value of H, with the formula

$$B_m = \frac{10^8 R K \rho}{2 n_s A} \quad \text{in which}$$

B = flux density in lines / □ cm

R = resistance of galvanometer circuit

K = galvanometer constant

ρ = " deflection in mm

n = number of turns on secondary coil

A = area of cross section of iron ring in □ cm

This gives the maximum value of B = B_m, for the intermediate values of B, decrease the flux H. from the maximum to the point desired and no reversal is necessary.

In the case $B_1 = \frac{10^8 R K \rho}{n_s A}$ in which B_1 is the difference between the maximum flux and the flux for the point desired. Then to obtain the flux for the point desired = B_2, we have $B_2 = B - B_1 =$

$$B - \frac{10^8 R. K. \rho}{n_s A}$$

Obtaining a number of values of B & H. in this manner, which are given below, we found upon plotting the accompanying B. H. curve

for the sample, that we obtained a hysteresis loop of small area and as this area represents the amount of energy lost by hysteresis, per cycle, we can see that this is a very good quality of iron for the purpose.

The data and results of this test are as follows:-

Primary Coil = 220 turns # 14 B & S

Secondary " = 660 " # 22 " " "

Weight of iron = 9.907 #

Inside dia. ring = 10.5" = 26.67 cm

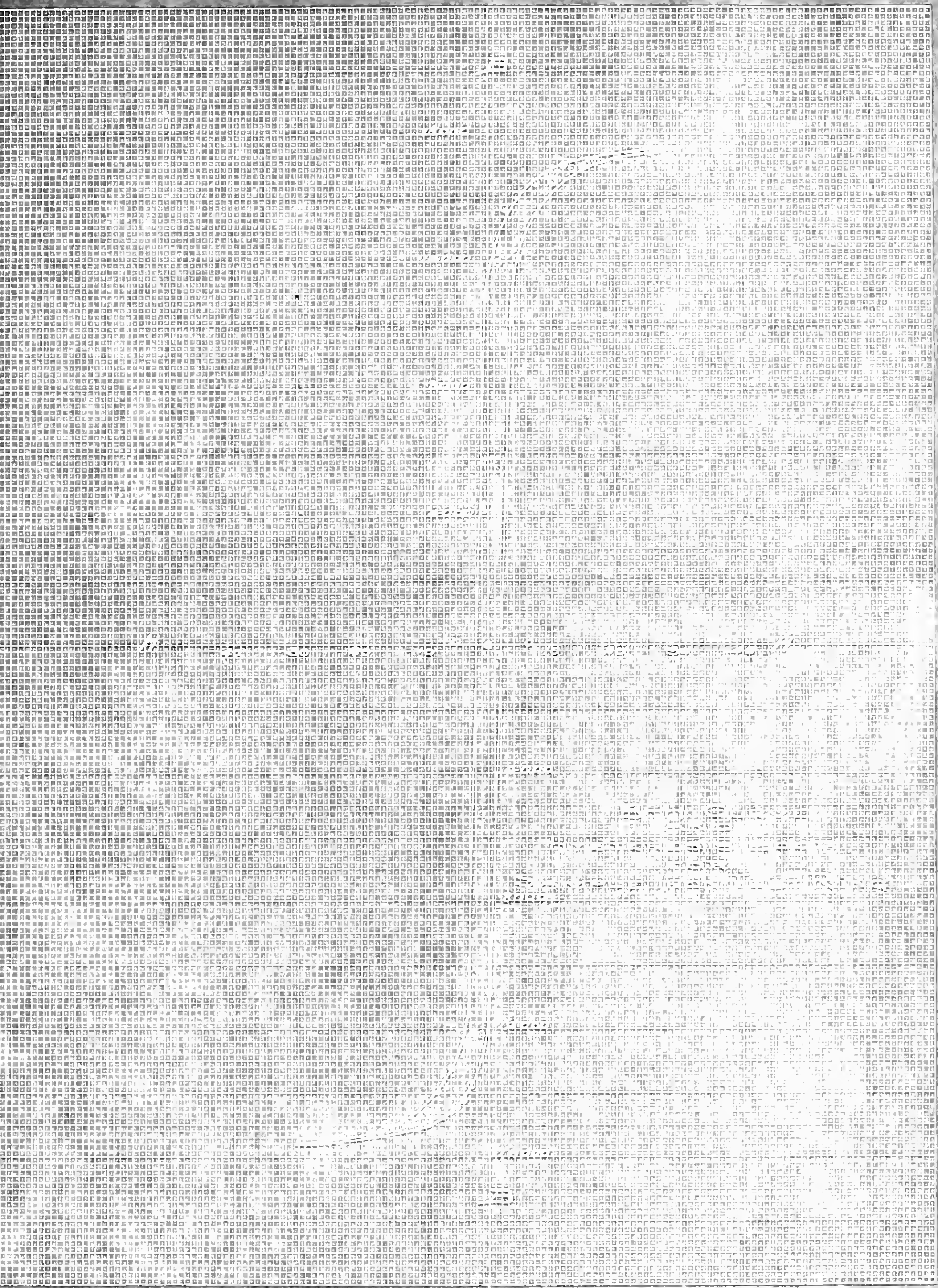
Outside " " = 12.5" = 31.78 cm

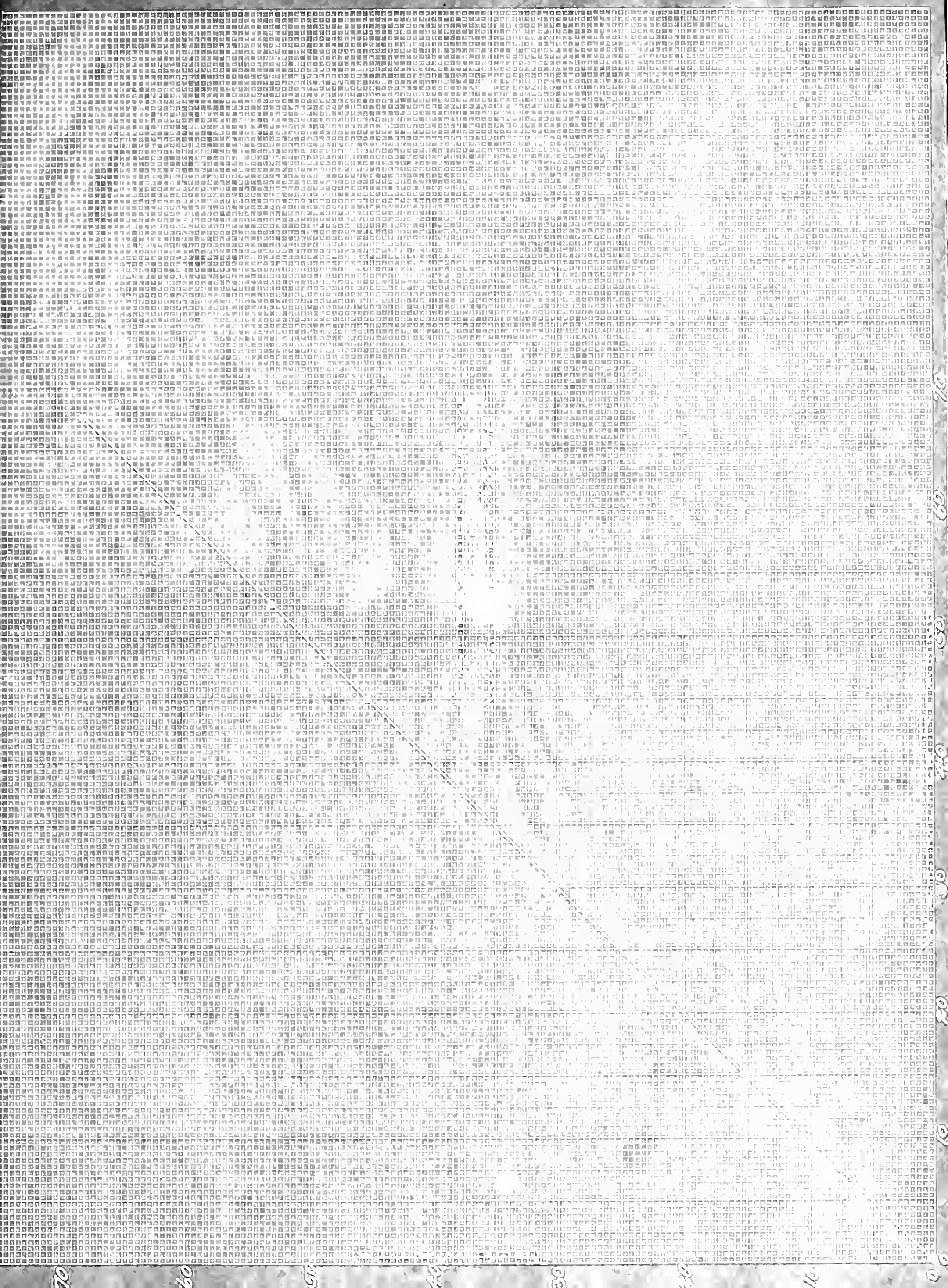
Area of cross section of ring = 6.37 □ cm

K = galvanometer constant = 45×10^{-10}

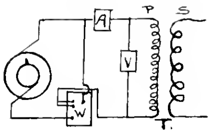
$$\text{Then } B_m = \frac{10^8 R K P}{2 N_s A} = \frac{10^8 \times 780000 \times 45 \times 10^{-10} \times 372}{2 \times 660 \times 6.37} = 15.520$$

I(amperes)	R (ohms)	ρ = def in mm	$\frac{I0^{8} R.K.P.}{n_s A}$	H	B lines /□cm
0	200000	2I5	46I0	0	I09I0
.5		I60	3425	I.565	I2095
I.0		84	I800	3.I40	I3720
I.5		6I	I307	4.7I	I4II3
2.0		5I.5	II03	6.28	I44I7
2.5		43.0	922	7.85	I4598
3.0		37.0	792	8.42	I4728
3.5		33.0	707	9.99	I48I3
4.0		23.0	492	II.56	I5028
4.5		24.0	5I4	I2.I3	I5006
5.0		23.5	503	I3.70	I50I7
5.5		20.0	428	I5.27	I5022
6.0		I7.0	364	I6.84	I5I56
6.5		I4.0	300	I7.4I	I5220
7.0		I0.0	2I4	I8.98	I5305
7.5	I00000	20.0	2I4	20.55	I5306
8.0		I5.5	I66	23.69	I5354
8.5					
9.0		5.0	54	26.83	I5466
9.5					
I0.0		0	0	30.07	I5520
-,0	700000	6I.5	4620	0	I0900
-.5		27I	20800	I.565	5280
-I.0		343	25700	3.I4	I0I80
-I.5		368	27600	4.7I	I2080
-2.0		383	28700	6.28	I3I80
-2.5	780000	347	29000	7.85	I3480
-3.0		352	29400	8.42	I3880
3.5		360	30I00	9.99	I4580
4.0		364	30400	II.56	I4800
4.5		365	30500	I2.I3	I4980
5.0		364.5	30450	I3.70	I4980
5.5		368.0	30700	I5.27	I5I80
6.0		365.0	30500	I6.84	I4980
7.0		366.5	30600	I8.98	I5080
8.0		369.5	30900	23.69	I5380
9.0		37I.0	3I000	26.83	I5480
I0.0		372.0	3I040	30.07	I5520



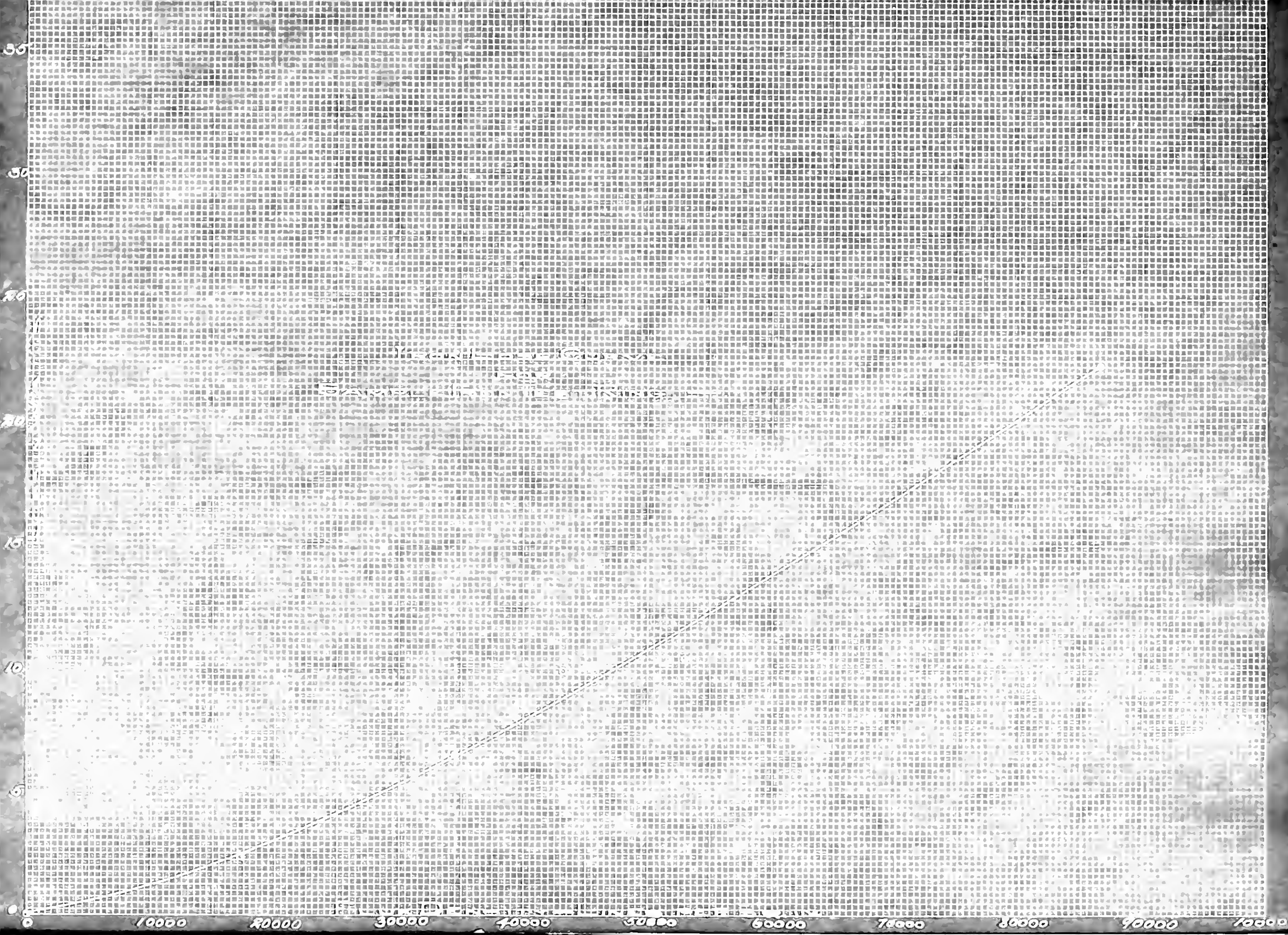


After determining that the iron was of a good quality for use in the construction of the transformer, we next determined the iron loss of the sample of iron, by the open circuit second-



ary method; the scheme of which is as shown in accompanying sketch. We know that with the secondary circuit of any transformer open, the only current which flows in the primary circuit is the exciting current, which is made up of two components at right angles; one the magnetising current, which is the current required to magnetise the core of the transformer and which is 90° behind the impressed E. M. F. and therefor the wattless component. The other component of the exciting current, is that required to make up for the iron losses in the machine. This current is in phase with the E. M. F. and the product of the two multiplied by the power factor, will give the iron loss in watts and is the reading of the wattmeter in the accompanying scheme. The results of this determination are as follows:

	Wattmeter reading	corrected			
Volts	Watts loss	Watts loss	B/□cm	I	B/□"
I0	2.3	2.3	2680	.30	17300
20	6.5	6.5	5360	.40	34600
25	9.5	9.6	6700	.45	43200
30	I0.5	I0.6	8240	.50	53200
40	I4.7	I4.8	I0720	.60	68000
50	24.3	24.5	I3400	.75	86500
60	33.7	34.0	I6080	I.I5	108[illegible]


0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
5
10
15
20
25
30
35

We used the secondary, or coil with greater number of turns, as the primary coil, because more accurate results were obtained than would be if we had used the other coil.

By varying the excitation of the generator we obtained the voltages impressed on the ring transformer, given in the first column of the data and also the corresponding readings of the exciting current and watts iron loss. The values of B. given are calculated with the formula $B = \frac{10^8 E}{\sqrt{2}\pi A f n_p}$, obtained from the general formula for the transformer given in a former part of this thesis.

We obtained a calibration curve for the wattmeter, given on the accompanying page, from which we found the correct watts corresponding to the reading taken.

Now we know that the iron loss varies directly as the volume of iron. By calculation we found the net volume of iron of the transformer to be 360 cu. in. The volume of the iron in the ring is 36.2 cu. in. By calculation the iron loss in the transformer was 2 % or 100 watts at a density of about 43000 lines per sq. in. From the iron loss curve for the ring, the iron loss at a density of 43000 lines per sq. in is 9.6 watts. As the volume of the ring is about I/IO of the calculated volume of the transformer iron. 9.6 x IO = 96 watts is the iron loss of the transformer as obtained in this manner, which agrees very closely with the calculated value.

As we expected to obtain the material for the construction

of the transformer from the Western Electric Co. of Chicago, we obtained a list of the sizes and styles of wire which they had in stock, from which we chose the sizes corresponding to the current densities and areas required for the coils of the transformer.

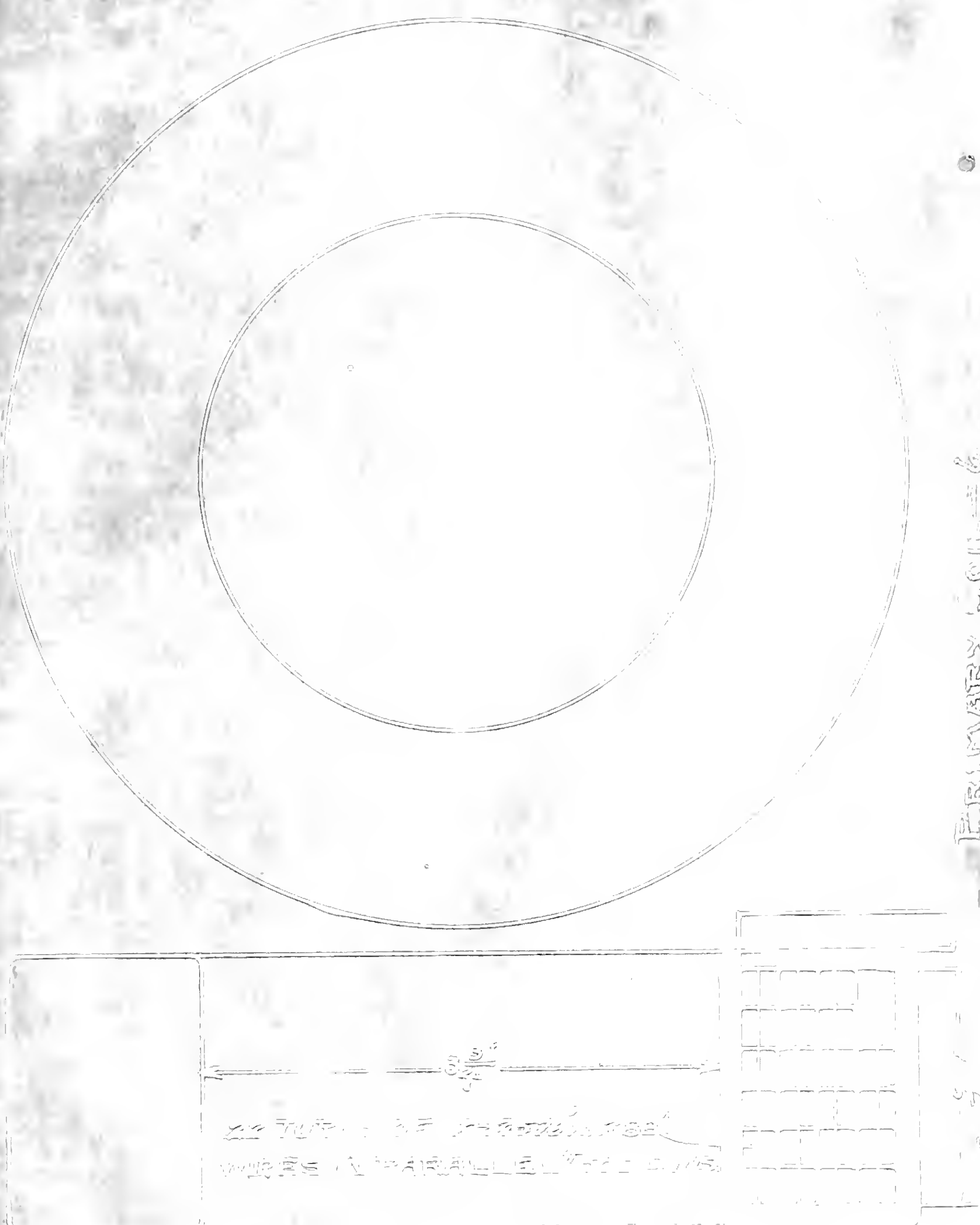
We finally settled upon the following, as the best suited for the construction of the transformer, taking into consideration both cost and time of delivery of goods to us.

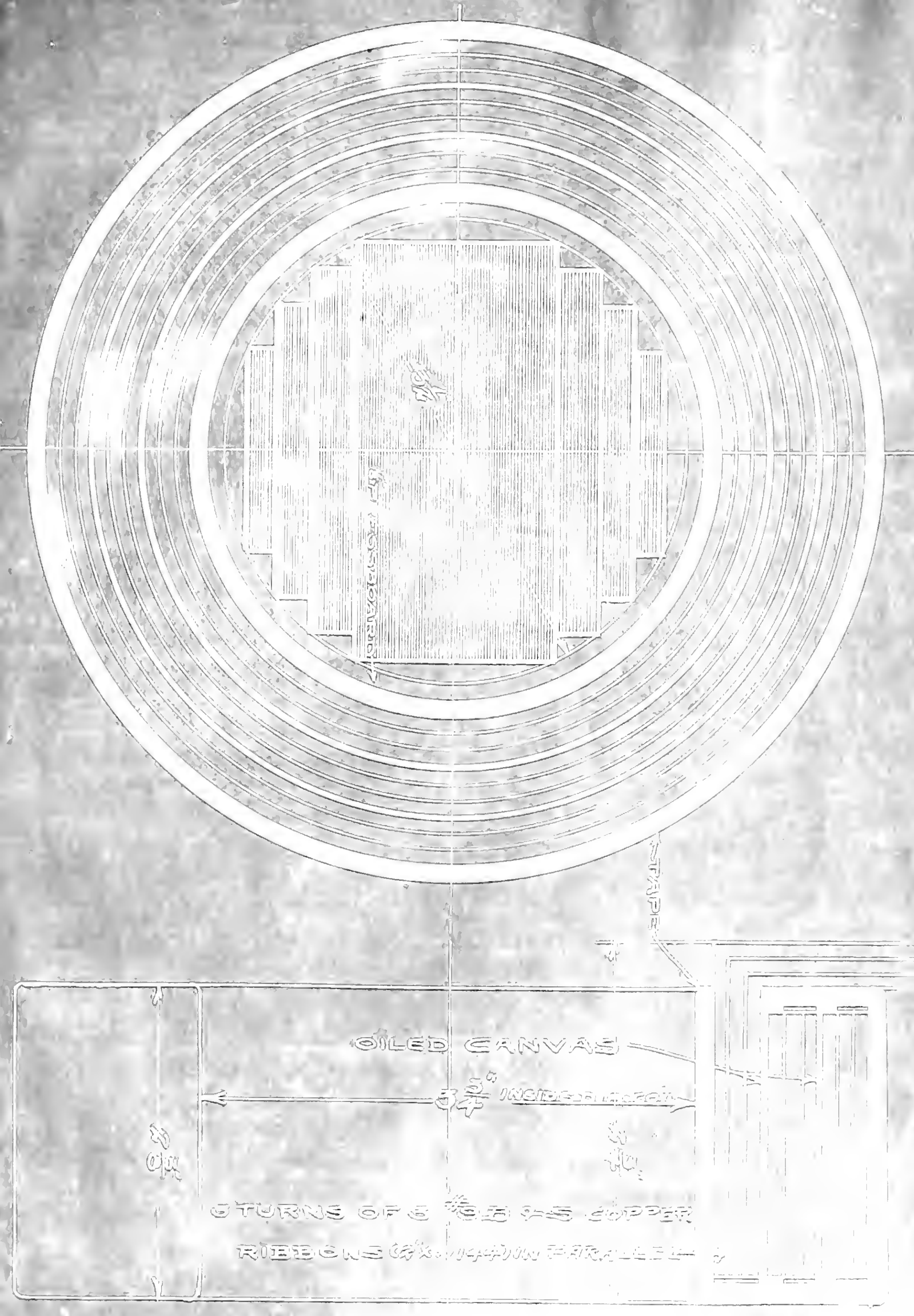
Primary coils (current density I500 ⊙ mils per ampere) I32 turns of # 2 square wire as shown in accompanying drawing. (We found later that we would have to change this to # 2 B. & S., # 60 Double Cotton covered round wire, as the cost of the former proved to be too great). We used six coils in series and 22 turns per coil.

Secondary coils - Current density I500 square mils per ampere.

Six turns of # [illegible] B. & S. copper ribbon, 2 - I" wide and 3 wires in parallel, making 6 ribbons in all and [illegible] turns per coil. Four coils to be connected either in series or in parallel. When connected in series, the secondary current is 500 amperes, and when connected in parallel the secondary current is I000 amperes.

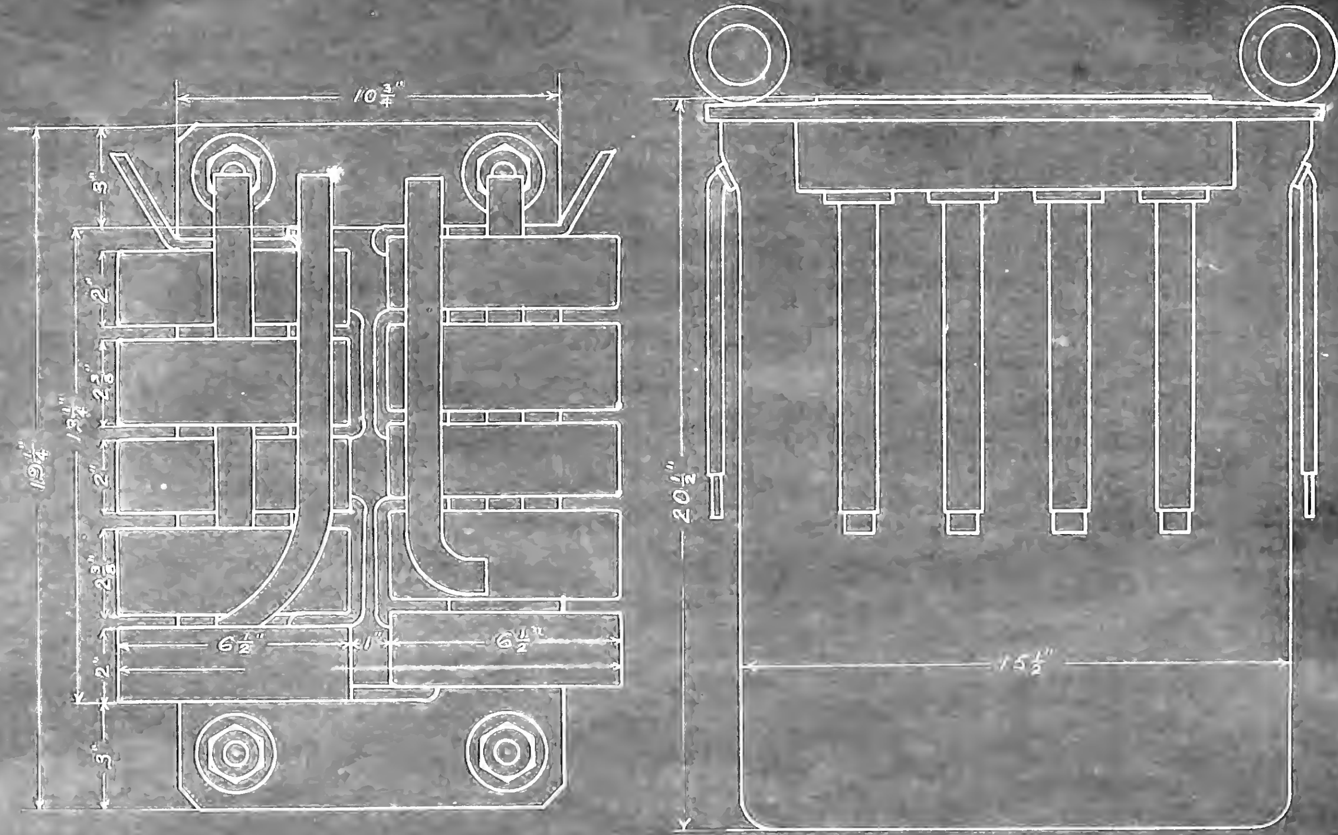
Assuming .0I5" as the thickness of the laminations, we found, by dividing the width of iron of each size by .0I5 the number of sheets of metal necessary for each part of the curve. For instance


PRIMARY COIL 6
WIRES IN PARALLEL

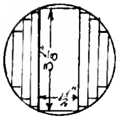


SECONDARY COIL-4

5 K.W. TRANSFORMER PUNCHINGS

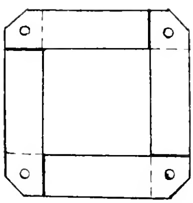


5 KW TRANSFORMER 110 V. PRIMARY 5 OR 10 V. SEC.



in [illegible] sketch [illegible] leg, [illegible] 7 1/3" wide, [illegible] to fill [illegible]" in [illegible] leg, [illegible] 3" for [illegible] legs.

Then $\frac{3}{.15}$ = 200 sheets [illegible] ery [illegible] acco- pa[illegible] dr[illegible]wing. [illegible] cons[illegible] in [illegible] core, a[illegible] to [illegible] extra ones on h[illegible]nd, in [illegible] of t[illegible] ov[illegible] e [illegible].



The [illegible] in the ac- com[illegible] sketch, [illegible] ch[illegible]ed with [illegible] ation of the joint a, a., so [illegible] joint will not come [illegible] e [illegible], [illegible] lamination, [illegible] would cause a sort o[illegible], [illegible] require a [illegible] exciting current and [illegible] decre[illegible]e [illegible] efficiency of the transformer.

[illegible] transformer [illegible] will appear when assembled i[illegible] by t[illegible] accompanying blue print.

The bo[illegible] legs of [illegible] assembled, t[illegible] bottom being clamped together [illegible] shown. [illegible] on each leg is [illegible], pressboard 1/8" thick. The coils are [illegible] on the outside of t[illegible], and the [illegible] upper part of the core is assembled and clamped as shown.